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THE IONIZING RADIATION AND HEATING OF THE UPPER ATMOSPHERE

by

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ABSTRACT

This paper considers the process of upper atmosphere heating by the wave and corpuscular ionizing radiation. Examination of the photochemical processes in the upper atmosphere allows judging about the distribution within it of temperature as a function of altitude. It is shown that about 40 percent of ionizing radiation energy passes to heat upon absorption in the atmosphere. The daytime ionizing radiation flux, estimated according to data on atmosphere heating, is of 3 to 12 erg/cm^2 sec.

The distribution of temperature with the altitude is computed in the night ionosphere. It is shown that the nighttime heating of the upper atmosphere may be induced by electrons with energy exceeding 100 eV, whose flux is $\sim 0.4 - 1.6$ erg/cm^2 sec. It is found that in nighttime the temperature is $\sim 700°$ K at 200 km, and $\sim 1130°$ K at 350 km.

* * *

Data on the motion of the Earth's artificial satellites point to the dependence of upper atmosphere density on the time of the day [1 – 3], on solar [4] and on geomagnetic activity [5]. In other words it may considered as demonstrated that the density of the upper atmosphere is function of the magnitude of the ionizing flux of solar corpuscular radiation absorbed in the upper atmosphere.

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* IONIZUYUSHCHEYE IZLUCHENIYE I RAZOGREV VERKHNEY ATMOSFERY.

This can be understood, if we take into account that the degree of ionization of atmosphere components at various altitudes, which depends directly on the flux of ionizing radiation, plays a substantial role in the formation of upper atmosphere's temperature regime. That of the ionosphere was lately analyzed by a series of authors [6 — 8]. In all these works the degree of heating was computed on the basis of data on density of the upper atmosphere, on the intensity of ionizing radiation and on the absorption cross sections of the latter by various gas components of the ionosphere. However, the present-day knowledge of photochemical processes in the ionosphere, taking place under the effect of ionizing radiation, provides the possibility to judge about the amount of the latter, necessary to sustain the given ionization level, originating from such fundamental characteristics of the ionosphere as for example the distribution of electron concentration and of the effective recombination coefficient in height.

It will be shown below, that the degree of upper atmosphere ionization exerts an effect on the degree of its heating, which points to a deep connection between the elementary processes taking place in the ionosphere and its thermal regime.

At present, the results of study of ion composition of the upper atmosphere with the aid of rockets and AES, may e explained, considering that the formation of atomic ions is the direct result of ionizing radiation's interaction with the upper atmosphere components, and that the neutralization of the ionized components of the upper atmosphere takes place by the dissociative recombination reactions of molecular ions. There lay between these two processes the intermediate processes of molecular ion formation, which take place by ion-exchange reactions of atomic ions with neutral molecules. The dissociative recombination reactions are more effective than the direct recombination of atomic ions, for their velocities are by 4 — 6 orders greater (as a function of height) than the rates of recombination of atomic ions [10].

Therefore, in the stationary case, the number of events of ionization in a certain volume is compensated by the number of dissociative recombination events of molecular ions according to the reaction

$$XY^+ + e \rightarrow X' + Y'' + E.$$

The recombination rate at a certain level in the ionosphere is given in this case by the expression $q = \alpha' n_e^2$, where $\alpha' = \alpha M^+/n_e$ is the effective recombination coefficient at that level, n_e is the electron concentration, M^+ is the concentration of molecular ions, α is the rate of dissociative recombination reactions of molecular ions.

The role of charge particle scattering in the distribution of ions in height is not taken into account in the work, and it is assumed that the ion-exchange reactions and the recombination of molecular ions take place at the same heights as the ionization does. It is understandable, that in equilibrium cases, the recombination reaction rate's magnitude is in this case equal to that of the ionization are at the given level.

If we admit after [11], that the energy consumed for the formation of a pair of ions at ionization by Sun's ultraviolet radiation, constitutes as an average 30 eV, the quantity $4.8 \cdot 10^{-11} \alpha' n_e^2$ ergs is the energy of ionizing radiation absorbed in a unit of time in a unit of volume at a certain level in the ionosphere.

Obviously, a specific distribution of electron concentration in height $n_e = n_e(h)$ may be sustained by a radiation, whose flux I (erg/cm^{-2} sec^{-1}) is equal at vertical incidence to

$$I = 4{,}8 \cdot 10^{-11} \int_0^\infty \alpha' n_e^2 \, dh.$$

It is possible to compute the distribution of temperature for various values of I. To that effect, the heat conductivity equation

$$E = -\lambda_0 \operatorname{grad} T, \qquad (1)$$

must be resolved simultaneously. Here E is the thermal energy flux expressed in erg/cm^{-2} sec^{-1}; λ_0 is the heat conductivity factor at a certain fixed level expressed in erg cm^{-1} sec^{-1}, and the equation of flux' continuity is

$$C_v \rho(h) \frac{\partial T}{\partial t}(h, t) + \operatorname{div} E = N(h, t), \qquad (2)$$

where ρ is the density; T is the temperature; t – the time ; N(h, t) is the thermal energy balance per unit of volume at a certain level h. The liberation of thermal energy, i. e. the positive part of the heat balance, will be definitely lower according to the degree of upper atmosphere ionization.

Two variants of the heat conductivity factor have been proposed by Nicolet [7]:

$$\lambda = 3{,}6 \cdot 10^2\, T^{1/2}, \quad \lambda = 1{,}8 \cdot 10^2\, T^{1/2}. \qquad (3)$$

Formulas (3) are given for a monoatomic gas and for a gas, consisting only of diatomic molecules respectively. Obviously, the values of λ for a concrete height must be written taking into account the correlation of atomic and molecular components at that height. Nicolet has also shown, that if instead of temperature we introduced a certain temperature parameter Θ

$$\Theta = \int_{T_0}^{T} \frac{\lambda}{\lambda_0}\, dT = \frac{2}{3} \frac{T^{3/2} - T_0^{3/2}}{T_0^{1/2}}, \qquad (4)$$

where λ_0 and T_0 are the values of the heat conductivity factor and the temperature at a certain fixed level of the atmosphere, the system of equations (1) and (2) could be transformed in a one-dimensional stationary case into an equation of the form

$$\frac{d^2\Theta}{dh^2} + \frac{N(h)}{A_h T_0^{1/2}} = 0, \qquad (5)$$

where A_h is the value of the factor at $T^{1/2}$ in formulas (3) at a certain height h.

Therefore, if we determine the thermal energy balance at a certain height h in a unit of volume, we may resolve the equation (5) relative to Θ and, utilizing formula (4), pass to distribution of temperatures in height. That is why we shall discuss below the question of heat inflow and outflow in a certain volume of the upper atmosphere.

It should be taken into account that not all the energy of ionizing radiation is consumed in the heating of the upper atmosphere. Nicolet [7, 12, 13] estimates, that the value of thermal efficiency varies from 25% at ionization by radiation with 584 Å wavelength to 60% when the ionization takes place at 304 Å wavelength. According to Hanson and Johnson estimates [14], 15 to 30% of energy of ionizing radiation pass to heat. Hunt and Van Zandt [8] fix this value between 6 and 50%. Because of the essential uncertainty of these values, we shall strive to provide a ceratin average estimate of the magnitude thermal efficiency, starting from the consideration of photochemical reactions taking place in the upper atmosphere. Let us note that this value probably depends on the height of the level considered, but it is, however, very difficult to estimate it at the present time. We shall thus consider our average estimate as true for all the considered heights, and the much the more so, since the error at the expense of such a simplification should not be great, as suggested in all probability in reference [8].

As already pointed out, the basic processes of atomic ion transition into molecular ions are apparently the ion-exchange reactions

$$O^+ + N_2 \rightarrow NO^+ + N, \quad O^+ + O_2 \rightarrow O_2^+ + O, \quad N^+ + N_2 \rightarrow N_2^+ + N.$$

The subsequent dissociative recombination of ions NO^+, O_2^+ and N_2^+

$$NO^+ + e \rightarrow N' + O'' + \Delta E, \qquad (6a)$$
$$O_2^+ + e \rightarrow O' + O'' + \Delta E, \qquad (6б)$$
$$N_2^+ + e \rightarrow N' + N'' + \Delta E \qquad (6в)$$

leads to vanishing of molecular ions and to the appearance of N and O atoms, whose kinetic energy is the direct thermal energu. This kinetic energy ΔE may be found from the equation

$$J_0 = B(X) + B(Y) + D(XY) + \Delta E, \qquad (7)$$

where J_0 is the ionization potential of molecular ions, standing in the left-hand part of equations (6); B(X) and B(Y) is the energy of the excited atom levels, having formed as a result of dissociative recombination; D(X, Y) is the dissociation energy of the corresponding molecule. It follows from the equation (7) that the greatest energy value in reactions (6a)— (6в), is respectively 2.5, 7.1 and 5.84 eV, if the atoms O and N are at their basic levels ^3P and ^4S, and if we estimate the energy of molecules' NO and N_2 dissociation as equal to 6.48 and 9.76 eV respectively [15]. The least values of energy will constitute 0.14, 0.94, and — 0.14 eV, if the atoms O and N are at the ^3P and ^2D levels in the reactions (6a), at the ^1D and ^1S levels in the reaction (6δ). The number — 0.14 eV means that even absorption of thermal energy of the medium can take place at dissociative recombination of the N_2^+ ion, if the formed atoms of nitrogen are situated at the ^2P and ^2D levels. Such reaction is possible, since the electron temperature in the F-layer is so high [14], that there is a sufficient number of electrons with energy of 0.14 eV.

In estimating the "thermal efficiency" of ionizing radiation it is necessary to take into account the possible yield of B(X) + B(Y) energy to heating, this energy being stored in the excited oxygen and nitrogen atoms. In the case when the product of reactions (6) are found at their own basic levels, this energy is evidently zero. In another case this energy constitutes in reactions (6) respectively 2.38, 6.16 and 6 eV.

If as a result of recombination processes n* (O) excited atoms were formed per unit of time in a unit of volume, the quantity (number) of atoms, losing the excitation energy to radiation, n*' (O) will be so much the smaller, that the probability of their thermal collision with other atoms is greater. The remaining atoms will lose energy in these collisions, i.e. it will go to atmosphere heating

$$n^{*\prime}(O) = n^{*}(O)\left(1 + \frac{\sigma\bar{v}n}{A}\right)^{-1},$$

where $\sigma\bar{v}n$ is the probability of collision; σ is the collision's deactivation cross section; $\bar{v}$ is the mean velocity of particles; A is the possibility of spontaneous transition; n — the concentration of particles.

An orientation computation of the quantity $\sigma\bar{v}n/A$, can for example be made for oxygen atoms situated in the state ^1D. For $O - O$ collisions $\sigma = 1.6 \cdot 10^{-15}\,cm^2$; $A = 7.3 \cdot 10^{-3}\,sec^{-1}$ according to [15]; is calculated by the formula $KT = 1/3\, m\bar{v}^2$; the values of n and T are taken from the atmosphere model of [16].

Calculation shows that the value $\sigma\bar{v}n/A \approx 6-7$, is already reached at 400 km, and at 350 km it is $\sim 19 - 20$. Therefore, the overwhelming part of excited atoms fail to de-excite practically in the whole ionosphere, and transfer their energy to heat.

It must be noted, that as a result of the ionization process a photoelectron is formed, its energy being significant. For example, at upper atmosphere ionization by quanta with 40 eV energy (HE II 304 Å), the photoelectron may have an energy of $\sim 26 - 27$ eV and yet produce a single ionization event. One may assume at oriented computations, that the residual energy, which is near 30% of that of the ionizing quantum, will be expended mainly on the excitation of the ^1D level of the atomic ox ygen, on account of the great excitation cross section of that level with electrons of $4 - 15$ eV energy, and of predomination of atomic oxygen at great heigths, i.e. according to the above-expounded, it will surrender it to heating.

In short, it may be said that if the mean energy expended on the formation of one pair of ions is 30 eV at ionization by UV-radiation, a value of the order of $12.5 - 17$ eV, or $40 - 60\%$ of that energy will go to heating.

Since according to Danilov [9], the absolute concentration of the ions NO^+ in the 200 – 400 km altitude range is 4 – 10 times greater than that of O_2^+ ions, and is greatly exceeding that of N_2^+ ions, the reaction (6a) will be more effective insofar as the energy liberation is concerned. That is why the value of the "thermal efficiency", which we shall denote by the symbol β, will be near 40%. Thus one may state that the liberation of thermal energy in a certain volume of the ionosphere will be expressed as the quantity of energy of ionizing radiation absorbed in the given volume and multiplied by the "thermal efficiency" say $\beta \cdot 4.8 \cdot 10^{-11} \alpha' n_e'^2$ erg/cm^3 sec.

Aside from heat conductivity, the energy loss by a certain volume of the ionosphere takes place mainly at the expense of infrared radiation of atomic oxygen by the reaction indicated by Bates [17]:

$$O(^3P_1) \rightarrow O(^3P_2) + h\nu \ (\lambda = 63 \text{ micron}).$$

The heat loss in this process is

$$L = n(O) \frac{1{,}68 \cdot 10^{-18} \exp(-228/T)}{1 + 0{,}6 \exp(-228/T) + 0{,}2 \exp(-325{,}3/T)} \text{ erg/cm}^3 \text{ sec} \qquad (8)$$

Therefore, the quantity N(h) erg/cm^3 sec in the equation (5) will be expressed by

$$N(h) = (\beta \cdot 4{,}8 \cdot 10^{-11} \alpha' n_e^2 - L). \qquad (9)$$

In order to determine the numerical value of N(h), it is necessary to assign oneself by a certain distribution in height of the quantities $\alpha' n_e$ and n(O). The question of contemporary state of knowledge concerning the altitude course of the quantity α' was discussed at length in reference [18]. Apparently, the experimental data obtained from measurements of n_e variations in the ionosphere during solar eclipse time, during ionospheric disturbances, in the course of a day etc... are most reliable in this regard.

The values of α' at various heights, borrowed from that reference, are compiled in the second column of Table 1 (next page). Data on the altitude course of n_e in the daytime ionosphere, measured with the help of rockets and artificial satellites, and whose compilation is given in ref.[19], are brought up in the third column of Table 1.

TABLE 1

Height km	α' $cm^3 sec^{-1}$	n_e cm^{-3}
500	$1\cdot10^{-10}$	$1\cdot10^6$
400	$2\cdot10^{-10}$	$1,2\cdot10^6$
350	$3\cdot10^{-10}$	$1,4\cdot10^6$
300	$5\cdot10^{-10}$	$1,5\cdot10^6$
250	$3\cdot10^{-9}$	$1\cdot10^6$
200	$2,5\cdot10^{-8}$	$4\cdot10^5$
180	$3\cdot10^{-8}$	$3\cdot10^5$
160	$4\cdot10^{-8}$	$2\cdot10^5$
140	$4,5\cdot10^{-8}$	$1,6\cdot10^5$
120	$5,6\cdot10^{-8}$	$1,3\cdot10^5$
100	$6,3\cdot10^{-8}$	$1\cdot10^5$

Unfortunately, there currently are very few data on direct measurements of atomic oxygen distribution in the upper atmosphere. We might point, for example, to the works by Pokhunkov [20] and Hineteregger [21]. Some data on the distribution of atomic oxygen are given in the work by Byram and al [22], who measured the distribution of molecular oxygen to 180 km height by a photometric method. Estimating that oxygen mass in a certain volume of gas is to these heights 20% of the mass of the total volume, we estimate, using the data of [22] on molecular oxygen, the atomic oxygen content to 180 km, using the equation

$$m_0\{2[O_2]+[O]\}=\frac{\rho}{5}, \qquad (10)$$

where m_O is the mass of the oxygen atom, $[O_2]$ and $[O]$ are respectively the concentration of the molecular and atomic oxygen, ρ is the density.

Alt. км	n (O), $см^{-3}$		
	(10)	[20]	[21]
100	—	$6,8\cdot10^{11}$	$6\cdot10^{11}$
110	$4\cdot10^{11}$	$2\cdot10^{11}$	$4,8\cdot10^{11}$
120	$1,2\cdot10^{11}$	$7,9\cdot10^{10}$	$2,2\cdot10^{11}$
140	—	$1,86\cdot10^{10}$	$5,3\cdot10^{10}$
160	$5,6\cdot10^9$	$6,5\cdot10^9$	$2,2\cdot10^{10}$
180	$4,2\cdot10^9$	$3,2\cdot10^9$	$1,5\cdot10^{10}$

TABLE 2

We compiled in Table 2 the data on atomic oxygen concentration computed by the equation (10), with the density borrowed from [16], the Pokhunkov data [20] and the data obtained from the curve brought out by Hinteregger [21].

As may be seen from Table 2, the data from [20] do not differ much from the orientation estimate, and in the 100 — 110 km range — from the data of [21].

At heights above 110 km, the discrepancy between the data of [20] and [21] increases, and reaches a factor of the order of 5 at 180 km.

However, Hinteregger himself recommends to exercise great care in using the curve brought up, which, as he writes, constitutes only an illustration of the method, and not a documentary material. Besides, Hinteregger points to the fact that the true concentrations of atomic oxygen might probably be below those he brought up. Taking all the above into account, we admitted for our computations the experimental data on atomic oxygen distribution of Pokhunkov [20]. Let us remark, that these data may have an uncertainty of the order of a factor of 2, which naturally may lead to an error in the estimate of temperature at any level. The magnitude of that error will be brought up below.

As may be seen from formula (8), the quantity L (h) depends on the distribution n (O) much more than on that of temperature, and that is why temperature data of [20] can be taken as a first approximation when computing L (h). We shall rewrite the expression (9)

$$N(h)=\beta P(h)-L(h), \qquad P(h)=4{,}8\cdot10^{-11}\alpha' n_e^2. \qquad (11)$$

The values of L and P for the daytime ionosphere, computed according to data of Table 1, using formulas (8) and (11) are compiled in Table 3. - This Table clearly shows that the liberation of thermal energy in the daytime ionosphere to 140 km exceeds the outflow at the expense of the microwave radiation of atomic oxygen, which, above 200 km can be altogether neglected.

TABLE 3.

HEIGHT, km	P	L
500	$4,8\cdot10^{-9}$	
400	$1,3\cdot10^{-8}$	
350	$2,9\cdot10^{-8}$	
300	$5,3\cdot10^{-8}$	
250	$1,5\cdot10^{-7}$	$<1,5\cdot10^{-9}$
200	$1,9\cdot10^{-7}$	$1,5\cdot10^{-9}$
180	$1,3\cdot10^{-7}$	$2,6\cdot10^{-9}$
160	$7,7\cdot10^{-8}$	$5\cdot10^{-9}$
140	$5,8\cdot10^{-8}$	$1,3\cdot10^{-8}$
120	$4,5\cdot10^{-8}$	$4,8\cdot10^{-8}$
100	$3\cdot10^{-8}$	$3,3\cdot10^{-7}$

The equation (5) is resolved at the following boundary conditions: we estimate that at 1000 km height there are no thermal fluxes of any kind, i.e. that

$$\left.\frac{d\Theta}{dh}\right|_{h=1000\ \text{км}}=0.$$

Considering that at the "zero" level, i.e. in our case at 100 km, the temperature is fixed and equal to T_0, we evidently obtain

$$\Theta\Big|_{h=100\ \text{km}}=0.$$

We admit T_0 at 100 km level as being equal to 212° K [16]. Approximating the function $N(h)/A_h T_0^{1/2}$ from the equation (5) by a certain function of h, we resolve the equation (5) relative to θ at several values of β. The temperature distribution with height will be obtained from formula (4) by utilizing the computed values of θ. The values of temperature computed for various β are plotted in the graph Fig. 1 hereafter.

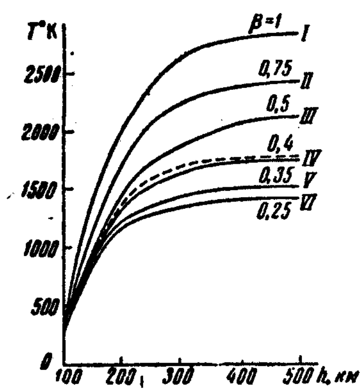

Fig. 1

If we take the standard temperature distribution with height for diurnal conditions according to [16] (dashes in Fig. 1), it can be seen that the best concordance with the computed curves will be obtained for $\beta = 0.4$, i.e. our ideas about the "thermal efficiency" resulted generally correct.

When determining the flux of ionizing radiation corresponding to temperature distribution with height computed for $\beta = 0.4$, it is necessary to take into account that the data on electron concentration, brought up in Table 1, are averaged results of measurements on rockets and satellites, carried out at $\sec Z = 2$, where Z is the zenithal angle of the Sun. This means that the flux of ionizing radiation, inducing a normal heating of the atmosphere corresponding to contemporary models, must constitute at vertical incidence

$$4{,}8 \cdot 10^{-11} \sec Z \int_0^\infty \alpha' n_e^2 dh = 5{,}8 \ erg/cm^2 sec. \qquad (12)$$

We may further conclude, that at $\beta = 0.4$, the curves I, II, III, IV, V, VI correspond to temperature distributions that would take place at fluxes of ionizing radiation, respectively equal to 14.5, 10.8, 7.2, 5.8, 5.0 and 3.6 erg/cm^2 sec. The precision of the calculation of the flux of ionizing radiation, causing either atmosphere heating, depends mainly on the precision in the determination of the quantity α'. It was shown by Danilov and Ivanov-Kholodnyy [23], that the uncertainty of the knowledge of the quantity α' may lie within the limits of a factor of 2. This means that the flux of ionizing radiation, defined by formula (12), may lie within the bounds of 3 — 12 erg/cm^2 sec.

Let us pass now to the computation of the distribution of temperature with height in the night ionosphere.

The existence of night ionization in the upper atmosphere layers, the dependence of electron concentration on geomagnetic latitude, the existence of local regions of increased ionization and numerous others features, point to the fact, that besides Sun's ultraviolet radiation there exists another source of ionizing radiation, whose effect does not cease at night, and which apparently has no connection with the Sun. A corpuscular hypothesis was brought forth in [24] in regard to night ionosphere ionization, according to which this ionization is induced by a flux of soft electrons with energies ranging from 100 to 5000 eV. On the basis of the data on the night ionosphere, the spectrum and the flux of these electrons was computed. It was found that the flux is of $\sim$1 erg/cm^2 sec. Similarly as was done for the daytime ionosphere, we computed the distribution of temperature with height in the night ionosphere. Contrary to daytime ionosphere, the mean energy expended on the formation of a pair of ions at irradiation by electron flux with 100 — 5000 eV energy, should be taken equal to $\sim$50 eV.

The distribution of the values of α' and n_e with height in the night ionosphere is compiled in Table 4 [next page]. The distribution of electron concentration with height at nighttime in the 80 — 200 km is given in the works [25, 26], and above 200 km — in [27]. The values of α' for the night are computed from the daytime values, taking into account the daily variation of density and electron concentration. Such method is expounded in [28]. The values of P were computed from these values of α' and n_e according to formula

$$P = 8 \cdot 10^{-11} \alpha' n_e \text{ erg/cm}^2 \text{ sec.}$$

The values of L in the night ionosphere are evidently identical to those in daytime ionosphere. The temperature values, computed for the night ionosphere by an identical method to that for the daytime ionosphere are compiled in the last column of Table 4.

TABLE 4

Height km	α' $cm^3 sec^{-1}$	n_e cm^{-3}	P erg cm^3 sec	L erg cm^3 sec	T^o K
500	$3 \cdot 10^{-10}$	$3 \cdot 10^5$	$2{,}2 \cdot 10^{-9}$		1190
400	$8 \cdot 10^{-10}$	$5 \cdot 10^5$	$1{,}6 \cdot 10^{-8}$		1160
350	$9 \cdot 10^{-10}$	$7 \cdot 10^5$	$2{,}4 \cdot 10^{-8}$		1130
300	$1{,}2 \cdot 10^{-9}$	$5 \cdot 10^5$	$3{,}5 \cdot 10^{-8}$		1070
250	$5 \cdot 10^{-9}$	$4 \cdot 10^5$	$6{,}4 \cdot 10^{-8}$	$<1{,}5 \cdot 10^{-9}$	955
200	$4 \cdot 10^{-8}$	$7 \cdot 10^4$	$1{,}5 \cdot 10^{-8}$	$1{,}5 \cdot 10^{-9}$	702
180	$4{,}5 \cdot 10^{-8}$	$2 \cdot 10^4$	$1{,}4 \cdot 10^{-9}$	$2{,}6 \cdot 10^{-9}$	606
160	$5 \cdot 10^{-8}$	$1 \cdot 10^4$	$4 \cdot 10^{-10}$	$5 \cdot 10^{-9}$	507
140	$5{,}5 \cdot 10^{-8}$	$8 \cdot 10^3$	$2{,}8 \cdot 10^{-10}$	$1{,}3 \cdot 10^{-8}$	400
120	$6{,}3 \cdot 10^{-8}$	$7 \cdot 10^3$	$2{,}4 \cdot 10^{-10}$	$4{,}8 \cdot 10^{-8}$	290
100	$6{,}3 \cdot 10^{-8}$	$4 \cdot 10^3$	$8 \cdot 10^{-11}$	$3{,}3 \cdot 10^{-7}$	212

The precision in the calculation of temperature distribution with height in the night and daytime ionosphere depends on the exactitude of the initial data on the distribution with height of atomic oxygen. This dependence is particularly great at computations of temperature distribution with height in the night ionosphere to 180 km, where the infrared emission of atomic oxygen is essential in the heat balance of a volume at a certain level of the ionosphere. As pointed out above, the data on atomic oxygen concentration, brought up in [20], may vary within the bounds of the factor of 2. The greatest errors in the computations of temperature, due to this uncertainty, may take place at night ionosphere levels to 180 km.

Computations show that if the concentration of atomic oxygen varies by a factor of 2, the errors in the distribution of temperature reach 24.5% at the 120 km level, and respectively 22.0%, 16% and 12.5% at 140, 150 and 180 km. At 200 km and above, where the atomic oxygen emission can be neglected, the aboslute error remains constant at $\sim$12% of the temperature value at 180 km, and the relative error decreases accordingly to $\sim 6\%$ at the 500 km level.

In order to sustain the ionization and the heating of the night ionosphere to the same degree as follows from Table 4, a soft electron flux

$$8 \cdot 10^{-11} \int_0^\infty \alpha' n_e^2 \, dh = 0{,}8 \quad \text{erg/cm}^2 \text{ sec}$$

is required. Taking into account that the uncertainty of the knowledge of the values of α' is of the order of the factor of 2, we may estimate that this flux lies within the bounds of 0.4 — 1.6 erg/cm^2 sec.

The computed temperature curves, agreeing with the data on upper atmosphere temperature available to us at the present time, point to the very great importance of a more extensive study of wave and corpucylar ionizing radiation in the upper atmosphere, including the photochemical processes therein, for they play a very important part in the process of ionosphere heating.

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**** THE END ****

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